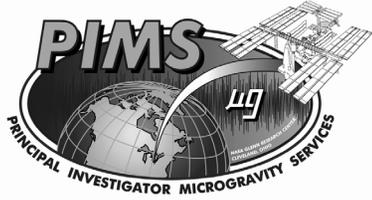


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# Section 5

## Developing microgravity tolerance specifications

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# Developing microgravity tolerance specifications



## GOAL:

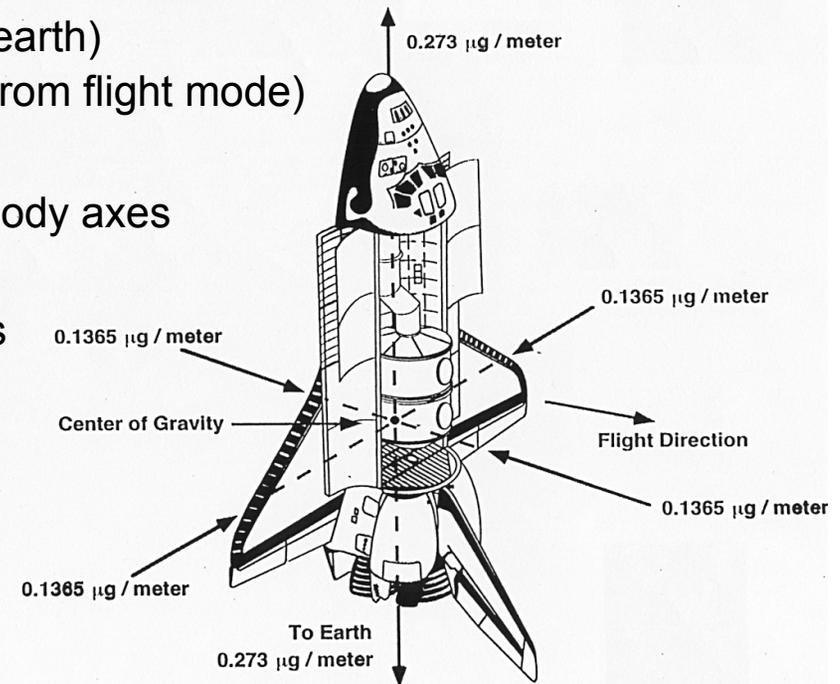
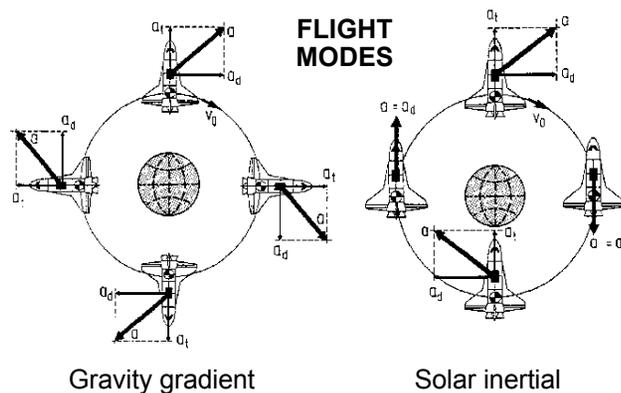
**Predict sensitivity of the experiment to the acceleration environment**

- PI must justify *need for microgravity*
- PI must be able to predict *tolerable* (and intolerable) *environments*

## PI's choices (and assignments) affect the quality of the $\mu g$ environment

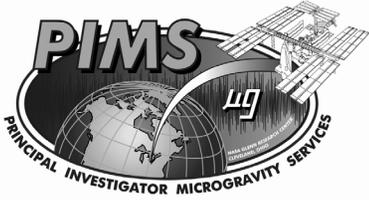
For the Shuttle, some variables are:

- **flight mode** (attitude of the carrier w.r.t. the earth)
- **deadband** (allowable angular displacement from flight mode)
- **location** of experiment relative to CG
- **orientation** of the experiment w.r.t. Shuttle body axes
- scheduling of **crew activities**
- operation of **other apparatus** or experiments

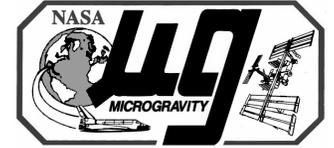


Horizontal and Vertical acceleration components for a point mass as a function of distance from Orbiter c.g. for a 300km altitude orbit.

- Feuerbacher et al. (1988)



# Developing microgravity tolerance specifications

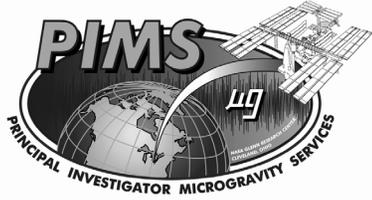


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## Strategy for assessing experiment sensitivity to the $\mu\text{g}$ environment

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- (1) Identify the *tolerance criterion*
- (2) *Correlate acceleration* to the tolerance criterion
- (3) Examine *knowledge base* from previous experiments
- (4) Perform “simple” analyses to determine *range of sensitivity*
- (5) Perform *detailed analysis* in the range of sensitivity and *examine specific microgravity environments*
- (6) If necessary and possible, *test hypotheses* with prototypes on ground-based microgravity facilities, e.g., KC-135, drop tower
- (7) Develop *detailed  $\mu\text{g}$  tolerance specifications*



# Developing microgravity tolerance specifications



## Choice of tolerance criteria

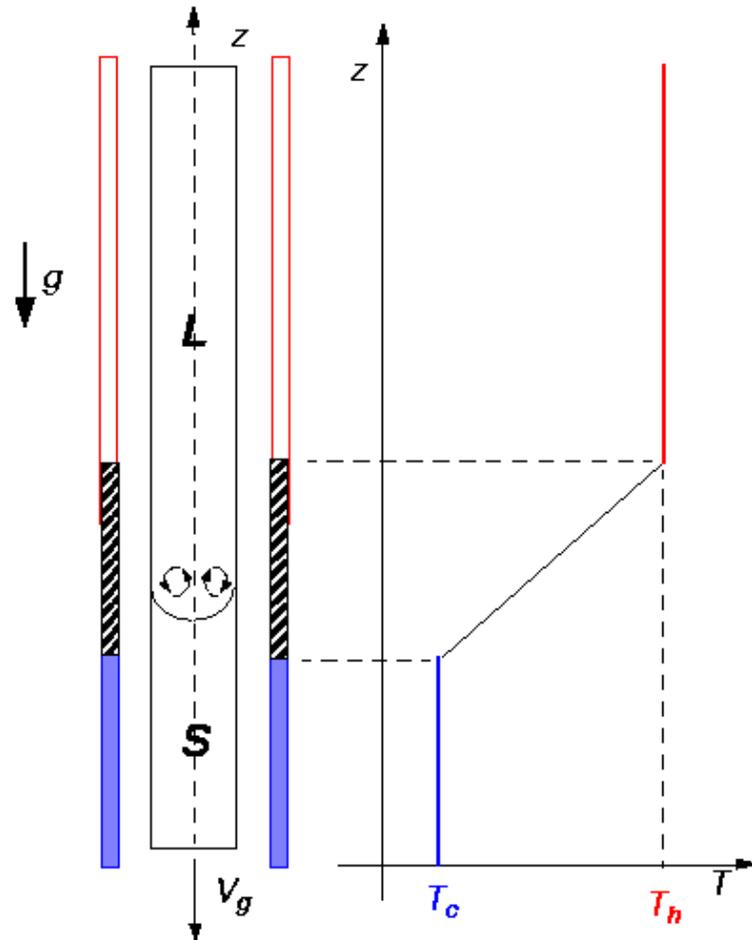
### Tolerance criteria are:

- **subjective**; may be to some extent **arbitrary**
- functions of **many parameters**
  - fundamental physics
  - experiment goal
  - composition of system (thermophysical properties, etc.)
  - geometry of system (aspect ratio, length of test section, etc.)
  - applied boundary conditions (applied thermal or pressure field, velocity of boundaries, etc.)
  - etc.



A good tolerance criterion is evaluated in light of the **specific experiment design** and the **specific environment** in which it is placed

## Bridgman growth of semiconductor crystals



Tolerance criterion:  
**5% variation in solute concentration**  
at solid/liquid interface (for example)

$$\xi = \frac{C_{max_{interface}} - C_{min_{interface}}}{C_{bulk}}$$



# Developing microgravity tolerance specifications



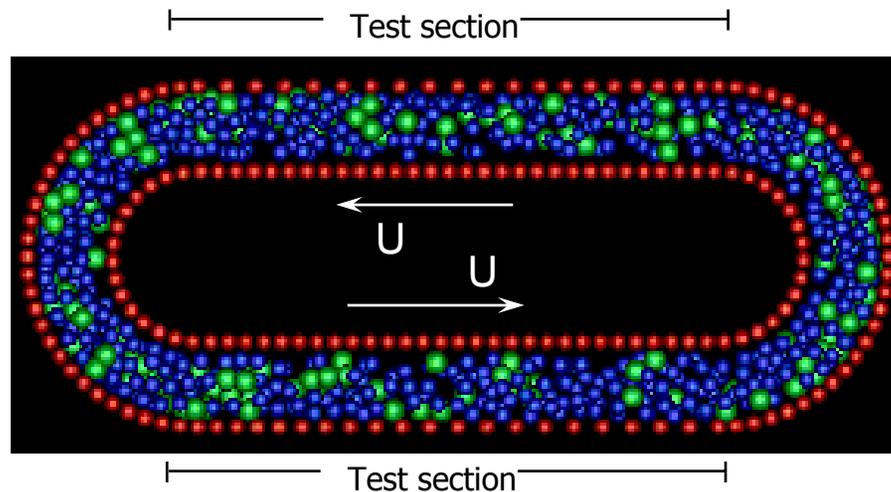
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## Correlating acceleration to tolerance criterion

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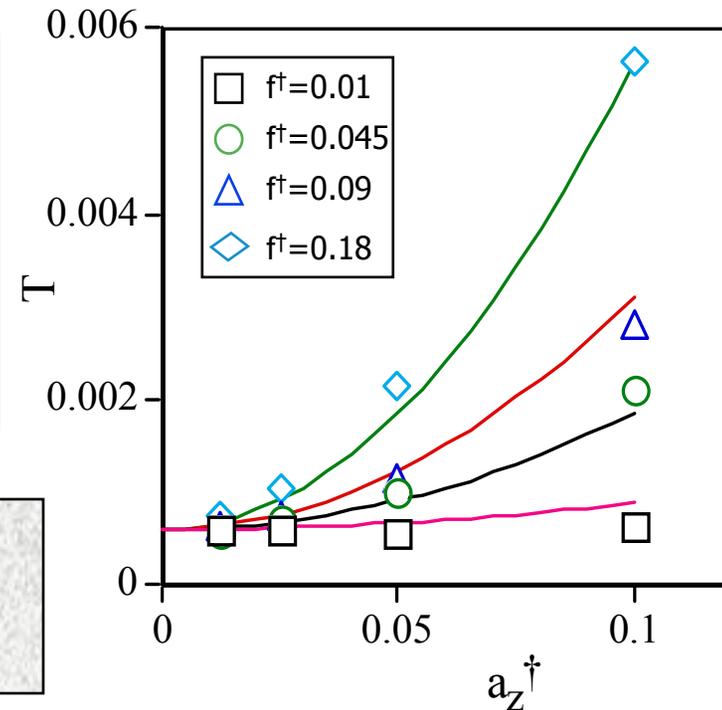
- All experiments will have some dependence on acceleration ***magnitude, frequency, orientation, and duration***
- Experimental system ***response varies enormously***, e.g.,:
  - requires an understanding of the ***time scales*** of the experiment relative to the unsteady acceleration environment
  - may be very sensitive to ***specific*** frequencies, orientations, e.g., interfaces
  - may require examination of ***overall*** momentum input, especially for bulk flows
  - may need ***long recovery times*** for short disturbances, especially for flows in which diffusion of momentum is large in comparison to the diffusion of the desired quantity (e.g., Schmidt or Prandtl number)

## Microgravity segregation of energetic grains ( $\mu\text{gseg}$ )



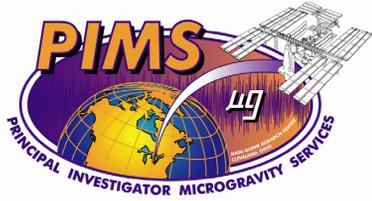
Tolerance criterion: g-jitter can contribute up to **5% variation in mean granular temperature,  $T$** , across test section

$$T = \frac{1}{3} \tilde{u}_i' \cdot \tilde{u}_i'$$



$$T = T_0 + c_i ft a^{\dagger 2}$$

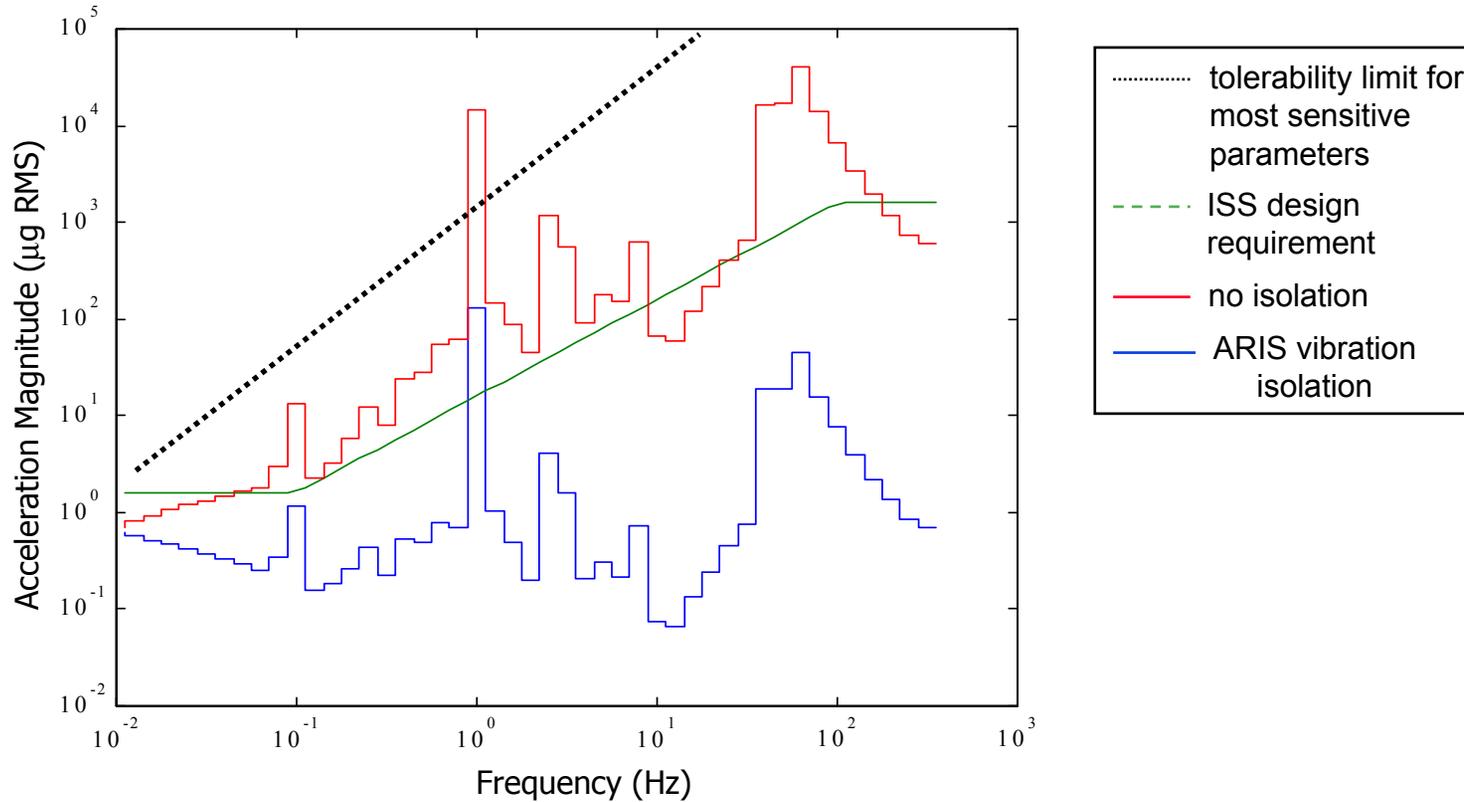
- Jenkins and Louge (1998)



# Developing microgravity tolerance specifications



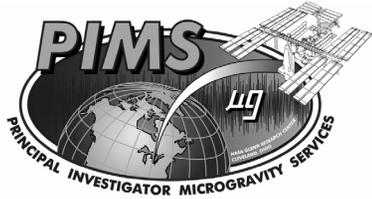
## Tolerability limits for $\mu\text{gSEG}$



- Jenkins and Louge (1998)

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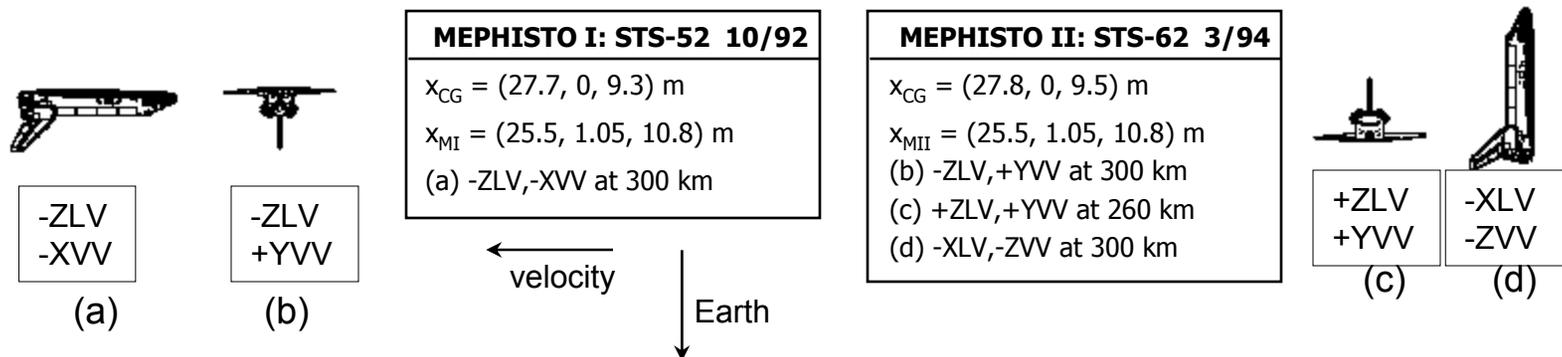


# Developing microgravity tolerance specifications

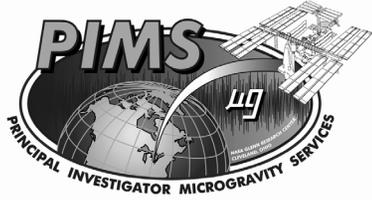


## Examine knowledge base: minimize g-jitter effects in directional solidification for MEPHISTO

- Use flight modes which do not require **Shuttle maneuvers** for water dumps, etc. (e.g., -ZLV,+YVV) for long-duration microgravity (>3 days)
- To minimize large accelerations, **specify a flight mode** requiring fewer thruster firings to maintain attitude; **2° deadband** required fewer thruster firings than 1° -- better  $\mu g$
- Experiments should be **aligned with Shuttle's z body axis** for these flight modes to minimize transient acceleration effects (least transmission of disturbances along this axis)



- de Groh and Nelson (1997)



# Developing microgravity tolerance specifications



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## Some microgravity environments

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### Carriers:

- International Space Station
- sounding rocket
- Space Shuttle
- free flyer
- drop tower
- parabolic flight, e.g., on KC-135

### Other distinguishing factors:

- **location** of experiment on the carrier
- **type of rack**
- **vibration isolation**
- **disturbances** present in the environment: crew exercise, thruster firings, water vents, other experiments



# Developing microgravity tolerance specifications

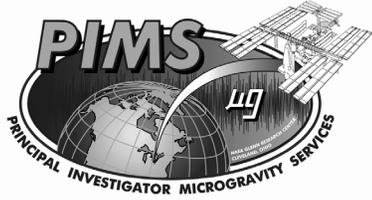


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## Developing detailed microgravity tolerance specifications

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- Describe the ***quasisteady*** acceleration limits
  - upper bound of QS ***magnitude*** (expect several  $\mu\text{g}$  on ISS)
  - desired ***orientation*** (if choices are available)
  - angular ***tolerance*** about that orientation (e.g., align experiment with torque equilibrium attitude (TEA) of ISS with a tolerance of  $\pm 0.05^\circ$ . Maintain  $\mathbf{g}_{\text{qs}}$  orientation to within TEA  $\pm 10^\circ$ )
- Identify ***oscillatory*** acceleration limits
  - ***specific frequencies*** at particular magnitudes of concern
  - frequency ***cutoffs*** (examine both upper and lower bounds)
- Describe ***transient*** acceleration limits
  - ***thumbs up/down for identified transients*** (based on thruster firings, impulsive crew activity, etc., e.g.,  $100 \mu\text{g}$  for up to 2 sec);
  - specify ***integrated acceleration input*** subject to limits (e.g.,  $300 \mu\text{g}\text{-sec}$  with magnitude  $\leq 150 \mu\text{g}$ )



# Developing microgravity tolerance specifications



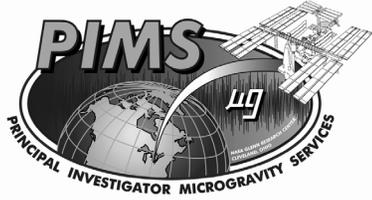
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## Developing detailed $\mu\text{g}$ tolerance specifications (cont'd)

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- Specify *duration* of experimental runs
    - *typical* length
    - anticipated *maximum/minimum* length
    - expected *number of runs* per 30-day microgravity period
  - Give *thumbs up/down for specific environments, e.g.*,
    - Shuttle, sounding rocket, free flyer, KC-135, ISS
    - examine possibilities for vibration isolation
      - isolated vs. unisolated rack
      - ARIS vibration isolation
      - passive vibration isolation
      - MIM, g-LIMIT, or other active sub-rack isolation unit
- and *specific disturbances*
- question experiments that are likely to interfere if run simultaneously (see DeLombard et al., 1998, for an example)

Now let's buzz through some examples: 



# Developing microgravity tolerance specifications



## Studies of Gas/Particle Interactions in a Microgravity Flow Cell

**Microgravity justification:** A continuation of  $\mu\text{gSEG}$ . The previous study was governed by particle-particle interactions. In this experiment, the gas medium (in which the particles move) can also have an impact. Numerical simulations of the evolution of granular temperature in a shear flow between parallel bumpy boundaries were used to determine the microgravity requirements. These simulations were informed by theory and tested in a KC-135.

**Microgravity requirements:**

**duration:** The minimum duration is governed by the time to reach steady state and by the amount of time to capture sufficient images for image processing and statistical analysis:

$$\theta_{\mu} > \theta_{ss} + \frac{N_{\min} d}{2U_{\max}} \quad \text{where} \quad \frac{\theta_{ss} U_m}{Y'} = \frac{42}{\sqrt{T_{ss}^*} [1 + 4G(v)] G(v)}$$

**quasisteady, oscillatory and transient:** similarly specific equations were developed

Also, tables of two choices of candidate materials were given which give values to the above parameters (see Science Requirements Document for the details).

- Louge and Jenkins (2000)

## Equiaxed Dendritic Solidification Experiment (EDSE)



**Microgravity justification:** Bulk convection has significant impact on dendritic growth on earth at an undercooling  $\Delta T < 1.5K$ . At this  $\Delta T$ , morphological details are very fine ( $< 1\mu m$ ); tip speed is high; and interactions are limited to distances of  $< 200 \mu m$ . Related experiment was able to obtain diffusion-controlled growth on the Shuttle for  $\Delta T = 0.2-1K$ , which provided grounds for optimism.

**Microgravity requirements:**

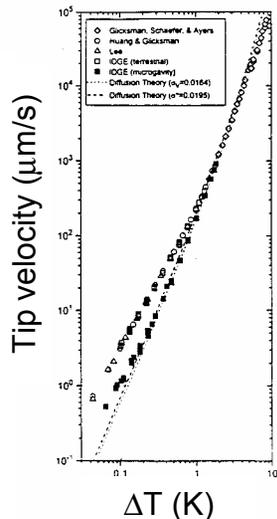
**duration:** 30-1000s

**quasisteady:** 30,000  $\mu g$  for  $\Delta T = 0.3K$ ; 760  $\mu g$  for  $\Delta T = 0.2K$ ; 2.3  $\mu g$  for  $\Delta T = 0.1K$

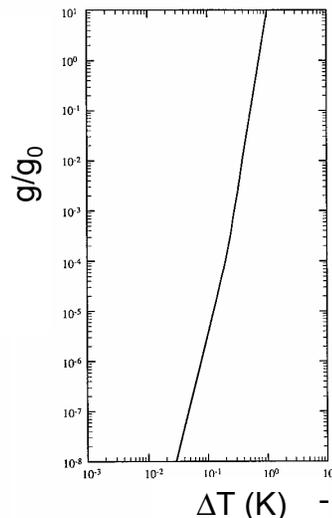
**oscillatory:** maximum 100  $\mu g$  at  $f < 0.5$  Hz; maximum 1000  $\mu g$  at  $f > 0.5$  Hz

Also, measure accelerations in vicinity of experiment with minimum bandwidth of 0-100 Hz with accuracy  $\pm 20\%$ ; time-tagged notification of accelerations outside specified levels

### Tetrahedron Arrangement of Dendrites

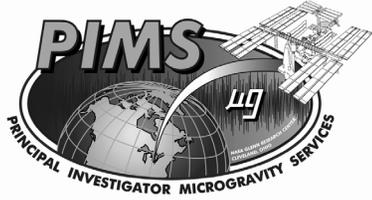


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- Sensitivity to g provided by Lee et al. (1996)

- Beckermann et al. (1998)



# Developing microgravity tolerance specifications



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## Physics of Colloids in Space (PCS)

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**Microgravity justification:** Growth of binary colloidal crystal alloys is driven purely by entropy; complexity of alloy structure places severe demands on the growth conditions.

- Extended duration is required for the growth process.
- Matched index of refraction between particle and medium required for diagnostics. On earth, density matching to avoid sedimentation effects is also necessary, which places a severe limitation on candidate materials.
- As fractal colloidal aggregates become more tenuous, they are increasingly fragile and are susceptible to shear forces, as well as collapse by their own weight. Order-of-magnitude estimate that 10  $\mu\text{g}$  and below will ensure that yield stress no longer limits cluster size.

**Microgravity requirements:**

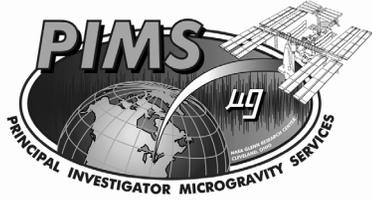
**duration:** app. 1 year

**quasisteady:** 1000  $\mu\text{g}$

**oscillatory:** most sensitive to low frequency, gives example of diagnostic to determine sensitivity during experiment. Cites previous successful colloidal crystal growth on the Shuttle

**transient:** maximum 10,000  $\mu\text{g}$  for a second or two

- Weitz and Pusey (1997)



# Developing microgravity tolerance specifications



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## Coarsening in solid/liquid mixtures (CSLM)

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**Microgravity justification:** Sedimentation places a lower limit on the allowable volume fraction of solid particles on earth. Below the critical volume fraction, a skeletal structure will not develop and the particle sedimentation distance is governed by Stokes law. Investigation by scaling analysis and using various model systems shows that reducing particle sedimentation distances to acceptable levels on earth is nearly impossible. Five hours of microgravity time is a realistic expectation of the required duration.

**Microgravity requirements:**

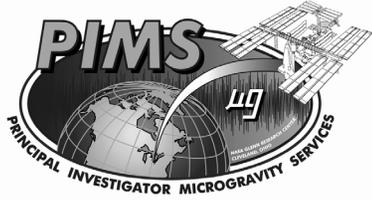
**duration:** 5 hours

**quasisteady:** less than 1000  $\mu\text{g}$  with no preferred direction

**oscillatory:** less than 10  $\mu\text{g}$  over  $f=0.1-20$  Hz

**transient:** less than 1000  $\mu\text{g}$  for no longer than 0.1 sec, with total integrated firing times less than 1.8 sec during the 5-hour period

- Voorhees et al. (1994)



# Developing microgravity tolerance specifications



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## Solid Inflammability Boundary at Low Speed (SIBAL)

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**Microgravity justification:** Theoretical analysis shows that flame spread and extinction in sub-buoyant low-speed flow (less than 20 cm/s) are fundamentally different from higher-speed flow typically encountered on earth. The scientific understanding of these phenomena, especially material flammability, is incomplete without investigating this low-speed regime. Examination of low-speed flow on flames at 1g is impossible.

Microgravity duration must be long enough for the flame to reach steady state, approximately 16 sec. Further, quench limit determination requires a gradual approach to the limit through a succession of steady states, requiring at least a minute. Residual acceleration must be small enough so that the flames are not perturbed by the induced flow.

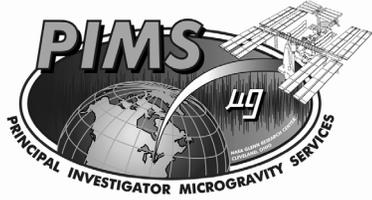
**Microgravity requirements:**

**duration:** 16 sec to several minutes

**quasisteady:** below 100  $\mu g$

KC-135 test was compromised at 10,000  $\mu g$ . Free-floating the payload gave promising results at a measured gravitational level of 100  $\mu g$ , but the duration was too short. Drop tower experiments also suffered from short duration.

- T'ien and Sacksteder (1995)



# Developing microgravity tolerance specifications



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## Smoldering Combustion Experiment in Space

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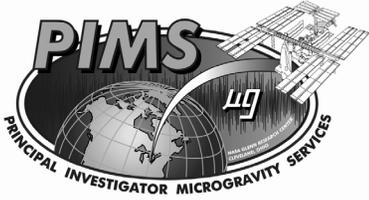
**Microgravity justification:** Smoldering combustion is poorly understood. Its complexity requires many modeling approximations and (ground-based) experimental compromises. Microgravity can simplify the problem greatly by minimizing buoyancy-driven instability and problems related to sedimentation and collapse of fuel and char.

- In 1D, opposed smolder air velocities of 3 mm/s and more weaken the reaction by convective cooling. Forward smolder air velocities that can overcome buoyancy can cause flaming of the material.
- Extreme sensitivity to  $g$  at smoldering occurs at porous solid/gas interface under many conditions
- Sensitivity of this naturally weak combustion reaction to heat losses and oxygen availability.
- Possible applications to fire safety

**Microgravity requirements:**

**duration:** at least 1000s

- Fernandez-Pello (1992)



# Developing microgravity tolerance specifications



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## Recap: Strategy for assessing experiment sensitivity to the $\mu\text{g}$ environment

---

- (1) Identify the *tolerance criterion*
- (2) *Correlate acceleration* to the tolerance criterion
- (3) Examine *knowledge base* from previous experiments
- (4) Perform “simple” analyses to determine *range of sensitivity*
- (5) Perform *detailed analysis* in the range of sensitivity and *examine specific microgravity environments*
- (6) If necessary and possible, *test hypotheses* with prototypes on ground-based microgravity facilities, e.g., KC-135, drop tower
- (7) Develop *detailed  $\mu\text{g}$  tolerance specifications*



# Developing microgravity tolerance specifications



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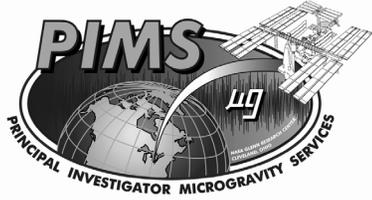
## Where to go for help online

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Browse through the microgravity sites to find experiments with similar physics:

- Fluid physics, materials science, combustion:  
**<http://microgravity.grc.nasa.gov/new/expermnt.htm>**
- Life sciences: **<http://lsda.jsc.nasa.gov>**, **<http://www.spaceline.usuhs.mil>**
- ESA microgravity database: **<http://www.esa.int/cgi-bin/mgdb>**
- Microgravity Research Experiments database (MICREX):  
**<http://mgravity.itsc.uah.edu/microgravity/micrex/micrex.stm>**
- NASA Technical Reports Server: **<http://techreports.larc.nasa.gov/cgi-bin/NTRS>**  
(especially RECONSelect)
- For NASA civil servants and contractors, try Aeronautics & Space Access Page (ASAP): **<http://www.sti.nasa.gov/ASAP>**

Note: for a good science dictionary, see <http://www.harcourt.com/dictionary> (?),  
**<http://biotech.icmb.utexas.edu/search/dict-search.html>**



# Developing microgravity tolerance specifications



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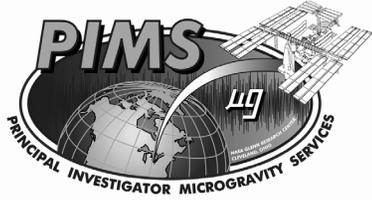
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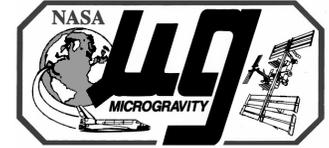
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# Developing microgravity tolerance specifications



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